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Measurements of identified particles anisotropic flow and deuteron production in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions by PHENIX

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Abstract. The v_2 and v_4 of pions, kaons and protons have been measured by PHENIX in 200 GeV Au+Au collisions up to p_T~6 GeV/c and 4 GeV/c, respectively. The v_4 of all these identified particles have been found to scale with the number of constituent quarks and all these particles have a similar v_4/v_2^2 ratio which is close to 0.9. The scaling behavior of v_2 is studied at high p_T and a deviation from the universal scaling is observed for transverse kinetic energy (KE_T/n_q) higher than 1 GeV. The coalescence parameter B_2 from deuterons production has been studied as a function of p_T and N_{part}.

Keywords: v_2, v_4, KE_T scaling, B_2
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1. Introduction

A hot, dense non-hadronic matter with strong interactions has been created at RHIC in ultra-relativistic heavy ion collision[1][2]. The anisotropic flow coefficients v_2 and v_4 provide sensitive information about the properties of the matter in the earliest stages of the heavy-ion collisions. The v_2 of identified hadrons has been found to obey empirical scaling with the number of constituent quarks (NCQ) for KE_T, which indicates that partons interact strongly with each other at early stage and hadronize through coalescence[3]. In this work, the measurement of v_4 will be used to further test this scaling. The v_4/v_2^2 ratio has been proposed as a probe of ideal hydrodynamics and related to the degree of thermalization[4] in the system. Accurate measurements of identified particles v_4/v_2^2 ratio will constrain the model calculations. At the high p_T the anisotropic emission of particles is dominated by parton energy loss[5]. And at the intermediate p_T, this anisotropy can be generated through the coalescence of shower partons with thermal partons[6]. So the NCQ scaling is expected to break since the energy loss mechanism affects all particle species similarly. Determining the breaking point in the NCQ scaling will provide information on the limits of applicability of the hydrodynamic description of the system dynamics. With a binding energy of 2.24 MeV, the deuteron is a very loosely bound state and formed only at the freeze out stage in the collision by the coalescence of proton and neutron. Therefor the deuteron production is a sensitive measurement to study the coalescence mechanism in momentum and spacial space and can provide information about the space-time evolution of the system.

2. Analysis Methods

During Run 7 of RHIC, the PHENIX experiment recorded 5.5 B minimum-bias 200 GeV Au + Au collision events and 2.2 B have been used for this work. Two new subsystem detectors were installed prior to Run 7, which significantly enhanced the PHENIX capabilities for identified particle anisotropic flow measurements . A time of flight detector(TOFw) was installed in the west arm of the PHENIX spectrometer. With $\sigma_t = 75$ ps intrinsic timing resolution, the TOFw detector allows pion/kaon separation up to $p_T \sim 2.8$ GeV/c, and kaon/proton separation up to $p_T \sim 4.5$ GeV/c. Together with the previously installed Aerogel Cherenkov counter (ACC), the TOFw detector provides high p_T hadron identification in PHENIX. Combining the photon yield measured in the ACC and the mass-squared from TOFw, the kaon identification is extended to $p_T \sim$ 4 GeV/c, while the pion and proton identification reaches $p_T \sim$ 7GeV/c. The Tofw also can identify the deuteron to $p_T \sim$ 5 GeV/c. PHENIX was also upgraded with a new reaction plane detector (RxNP) which covers the rapidity region $1.0 < |\eta| < 2.8$ with best resolution around 74% for v_2 measurements. Since the RxNP is installed away from mid-rapidity, the non-flow effects from jet correlation are relatively small.

2.1. Results

Figure 1 shows the v_4 of pions, kaons and protons in the $20 - 60\%$ centrality bin in 200 GeV Au+Au collisions. In the left plot, the v_4 is shown as a function of p_T. A clear mass ordering is observed for pions, kaons and protons, which is consistent with hydrodynamics behavior which has been previously observed for the elliptic flow. In the middle plot, the v_4 measurements are presented as a function of transverse kinetic energy $KE_T = m_T$-m_0. In this unit, the mass ordering disappears at low KE_T which is consistent with hydrodynamic predictions. For KE_T greater than about 0.5 GeV, kaons and pions show much less v_4 than protons. A universal behavior for baryons and mesons is observed when KE_T is divided by the n_q (number of constituent quarks) and the v_4 values are divided by the nq^2. This universal behavior has also been observed in the measurements of v_2 for identified hadrons[3]. The results presented here further strengthen the conclusion that partonic flow has been built up in the early stages of the heavy-ion collisions at RHIC.

Figure 2 shows the v_4/v_2^2 ratio for pions, kaons and protons as a function of p_T

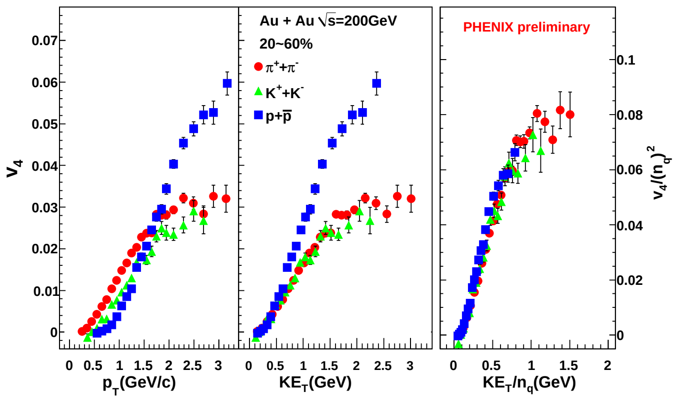

Fig. 1. The v_4 of pions, kaons and protons for $20-60\%$ Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

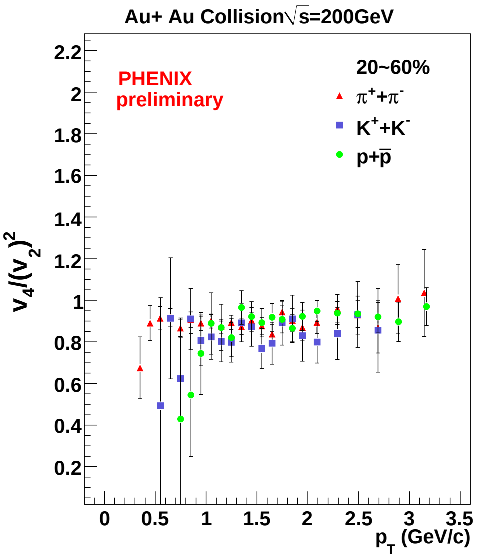

Fig. 2. The v_4/v_2^2 for pions, kaons and protons as a function of p_T in the $20-60\%$ centrality class in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions.

in the $20-60\%$ centrality bin. This ratio is flat with p_T in the measured range and is independent of the particle species within errors. We analyze the results in terms of a simple coalescence model:

$$\frac{v_{4,m}(2p_T)}{v_{2,m}^2(2p_T)} = \alpha(\frac{1}{4} + \frac{1}{2}\frac{v_{4,q}(p_T)}{v_{2,q}^2(p_T)}) \tag{1}$$

$$\frac{v_{4,b}(3p_T)}{v_{2,b}^2(3p_T)} = \alpha(\frac{1}{3} + \frac{1}{3}\frac{v_{4,q}(p_T)}{v_{2,q}^2(p_T)}) \tag{2}$$

where $v_{4,m}(p_T)$, $v_{4,b}(p_T)$ and $v_{4,q}(p_T)$ represent the meson, baryon and quark v_4 respectively, and $v_{2,m}(p_T)$, $v_{2,b}(p_T)$ and $v_{2,q}(p_T)$ represent the meson, baryon and quark v_2. Using the measured v_4/v_2^2 ratio around 0.9 for both baryons and mesons, from equations (1a) and (1b), we obtain that the parton $v_{4,q}/v_{2,q}^2$ ratio is around 0.5 and the parameter α is around 1.8. This result indicates that a thermalized partonic liquid has been produced at RHIC.

Using the high p_T elliptic flow results, we can study the limits of applicability of the hydrodynamic description. Figure 3 shows the v_2 of pions, kaons and protons as a function of KE_T in two centrality bins. Both v_2 and KE_T have been divided by the n_q. The left plot is the result in the $0-20\%$ centrality bin, and the right plot is the result in the $20-60\%$ centrality bin. In $20-60\%$ collisions, the NCQ scaling begins to break as the KE_T/n_q exceeds $\sim$1 GeV. This indicates that the origin of the v_2 is based in hydrodynamics collective flow and parton recombination in the low KE_T region, but above $KE_T/n_q \sim 1$ GeV, the contribution from parton energy loss become increasingly important.

If deuterons are formed by the coalescence of protons and neutrons, the invariant deuteron yield can be related to the primordial nucleon yields as[7]:

$$E_d \frac{d^3N_d}{dp_d^3}\bigg|_{p_d=2p_p} = B_2 \left[E_p \frac{d^3N_p}{dp_p^3}\right]^2 \tag{3}$$

where B_2 is the coalescence parameter. The above equation includes an implicit assumption that the ratio of neutrons to protons is unity. The p and $\bar{p}$ measured in[8] and in conjunction with the d and $\bar{d}$ presented here, are used to extract the coalescence parameter. Figure 4 shows $1/B_2$ as a function of N_{part} for two fixed p_T bins. The B_2 in more central collisions is large than the peripheral collision which implies that the average relative separation between nucleons increases in large sources, thus decreasing the probability of coalescence. The B_2 at p_T=3.0GeV/c is larger than the B_2 at p_T=1.5GeV/c, which is consistent with an expanding source and high p_T particle escape earlier than the low p_T particle. The coalescence parameter B_2 can also be used to obtain the source size at freeze-out. Thermodynamic models[7] predict that $1/B_2$ scales with the effective volume of the source. In Figure 4, the data show a linear rise of $1/B_2$ as a function of N_{part}.

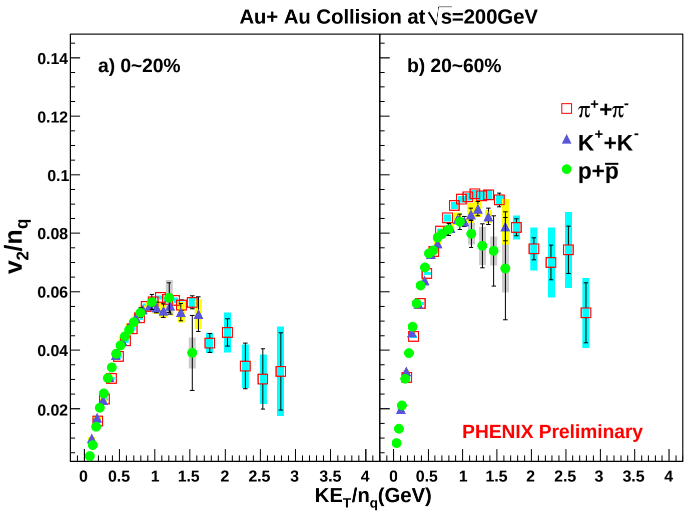

Fig. 3. Constituent quark scaling of elliptic flow, v_2 for pions, kaons and protons as a function of transverse kinetic energy per quark (KE_T) measured in two centrality classes:(left)$0-20\%$, and (right) $20-60\%$.

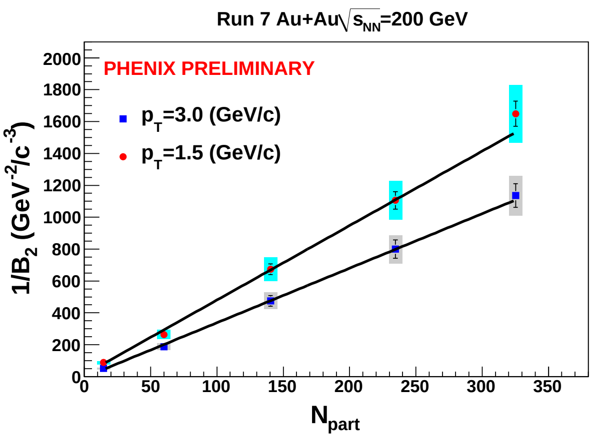

Fig. 4. $1/B_2$ as a function of N_{part} for two fixed p_T bins

3. Conclusions

The measurements of pion, kaon and proton v_2 and v_4 have been extended up to a p_T of 6 GeV/c and 4 GeV/c respectively by PHENIX. The NCQ scaling has been tested for v_4 and been found to hold for KE_T/n_q up to 1 GeV, indicating that partonic flow governs the bulk dynamics in heavy-ion collisions at RHIC. The mesons and baryons have a similar ratio of v_4/v_2^2, which is consistent with expectations for a thermalized partonic system in which hadrons at the intermediate p_T region are produced by parton recombination. The v_2 measurement shows that the NCQ scaling begins to break for KE_T/n_q above 1 GeV in the $20-60\%$ centrality class, which suggests that hard-scattering may be the dominant production mechanism for both baryons and mesons in this KE_T/n_q range and thus parton energy loss effects play a significant role in generating the azimuthal anisotropy in particle emission. The extracted coalescence parameter B_2 from deuteron production increases with p_T while decrease with N_{part}, which agrees with the idea of an expanding source.

Acknowledgments

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